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Science

Geo-archaeology of the Grozzana area (N–E Italy)

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ABSTRACT
The extensive analysis of remote-sensed data (among which ALS-derived images) and fieldwork carried out in the Trieste Karst (N–E Italy) have shed light on archaeological landscapes largely unknown until recent years. The chronological definition of this complex palimpsest was based on the collection of findings associated to the archeological evidence, shape and orientation of detected structures and stratigraphic relations among features. This allowed to evaluate the interplay between landforms through time and to reconstruct some long-term economic strategies pursued by past communities. As a result, we present a 1:5000 map of the easternmost sector of the Trieste area, next to the border between Italy and Slovenia, approximately corresponding to the area of the map Carta Tecnica Regionale 'Grozzana'. The map aims at providing a tool for the protection of the cultural and environmental heritage, land use planning and touristic valorization of the area.

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ALS; Karst; Italy; Slovenia; landscape; geomorphology

1. Introduction

In recent years, the extensive analysis of remote-sensed data and systematic fieldwork carried out in the Trieste Karst (N–E Italy) have revealed a complex palimpsest of archaeological landscapes that was largely unknown (Bernardini et al., 2013, 2015, 2018a, 2018b; Vinci & Bernardini, 2017; Bernardini, 2019). In this research, a crucial role has been played by the extensive application of Airborne laser scanning data (ALS) which has become of paramount importance to detect either archaeological or geomorphological features in forested areas.

The chronological definition of the identified features allowed to relate anthropogenic and natural processes and to recognize traces of the interaction between man and environment developed in the area through time. In the easternmost sector of the Trieste area, next to the border between Italy and Slovenia, the widespread presence of several archaeological remains dating back to different periods makes this area particularly suitable for investigating the evolution of the landscape.

We present here a high-resolution map of the area around the village of Grozzana/Gročana (Figure 1(B); Main Map), which provides a detailed description of the archaeological remains identified in last years as an integrated part of the karst landscape. The map approximately corresponds to the 1:5000 map (CTR n. 110151) of the Carta Tecnica Regionale of Friuli Venezia Giulia (Regione Autonoma Friuli Venezia Giulia [RAFVG], 2003). This map format makes the proposed cartography suitable to be extended to the entire regional territory.

2. Studied area

The studied area is about 10 km² in size and is located in the south-eastern part of the Classical Karst Region which is bordered to the W by the Gulf of Trieste, to the N–W by the Friuli Plain, to the E by Slovenia and to the S by the Istrian peninsula (Figure 1(A,B)). The investigated area is dominated by a karst plateau belonging to the Paleogene sequence of the Adriatic Dinaric Platform outcrop (Vlahović, Tišljar, Velić, & Maticec, 2005). Here, the anticline axis of the Classical Karst dips toward S–E and the azimuth of strata turns from N–W/S–E toward W–E (Biolchi, Furlani, Covelli, Busetti, & Cucchi, 2016; Furlani et al., 2016). The lithology of the area is characterized by a thick carbonate platform formed from the early Cretaceous to the early Eocene followed by the Eocene Flysch (Jurkovšek et al., 2016 with refs.; Main Map). The plateau has an average height of about 380 m a.s.l. slightly tilted towards N–W. The highest peaks in the studied area are Mt. Obrovnik (700 m), Mt. Cocusso/Kokoš (672 m) and Mt. Goli (620 m), located respectively in the north-eastern, north and south-eastern part. In the southern sector, steep slopes and narrow dry karstic valleys decline towards the Trieste gulf. A narrow valley N–E/S–W oriented is present S of the modern village of

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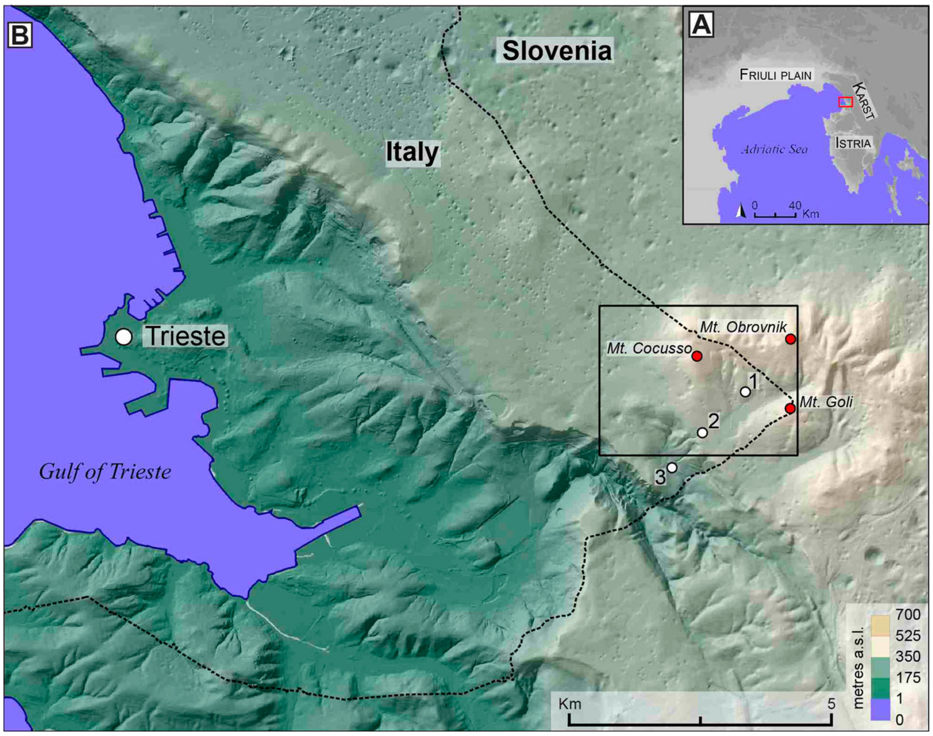

Figure 1. (A) The position of the investigate area (red line box) within the north-eastern Adriatic regions. (B) The investigated area (black line box) within the Trieste Karst and the indication of the main localities mentioned in the text: Grozzana (1); Pesek (2); Draga S. Elia (3).

Grozzana between Mt. Cocusso and Mt. Goli (Figure 1 (B)). The vegetation mainly consists of woodlands interspersed with brushes and grassland which extend over large areas. Besides a few small artificial ponds, no permanent surface water or rivers occur in the studied area. A number of caves are reported (RAFVG, 2017) as well as several dolines (Main Map).

3. Methods

The map is the outcome of the GIS-based combined analysis of remote-sensed data (ALS-derived images and aerial imagery), historical maps and fieldwork consisting of systematic surface and pedological surveys carried out between the beginning of 2015 and the end of 2018.

ALS data, originally provided by Helica Company for the Civil Protection of Friuli Venezia Giulia using a Laser Terrain Mapper (ALTM) Optech 3100 mounted onto a helicopter AS350 were acquired with an average precision of 4–5 measurements per square meter. The final DTM used for digitizing was characterized by a cell size of 1 m^2 and a vertical accuracy of ± 0.15 m.

Data have been processed and analyzed following the methodology developed in other areas of Trieste Karst and described in previous contributions (Bernardini, 2019; Bernardini et al., 2015, 2018a, 2018b; Vinci & Bernardini, 2017). All recognized features were systematically checked on the ground to verify the state of conservation and the building technique of the structures and to identify possible stratigraphic relations with other structures and archaeological finds scatters.

The archaeological features detected through ALS generally consist of landforms completely absorbed by the physical environment. These can be recognized on the ground by the presence of small topographic ridges generally up to 1 m high buried by earthen soil and vegetation (Figure 2). In many relevant cases, field walking led to the collection of some diagnostic artefacts. These findings, associated with the shape, the orientation and, oddly, the building techniques of buried structures, allowed to propose a chronology for many features. In other cases, a relative chronological attribution was proposed on the basis of stratigraphic relationships between features. In past decades, cross-cutting relationships have been considered as reliable chronological markers in landscape studies in floodplain environments (e.g. De Guio et al., 1999, 2009) and are being taking on increasing importance with the expanding application of ALS (Draganits et al., 2015; Vletter & Schloen, 2016).

In the examined area, most of the stratigraphic relationships are provided by the visual comparison between detected features and the early nineteenth century Franciscan Cadastral Maps (hereafter FCM). This allowed to consider all features covered or cut by features (especially dry-stone masonry, field divisions and paths) recorded in the FCM to be earlier than the nineteenth century. All gathered chronological information allowed to define the chronology of the features according to the spans presented in Table 1.

Figure 2. Parallel relict wall structures attributed to the Roman period visible on the field as ridges in the north-western part of the investigated area, corresponding to a large possible Roman building (Main Map, n. 4). View from W.

Geological and geomorphological information were drawn from previous relevant literature (Cucchi e Piano, 2013; Jurkovšek et al., 2016), ALS data interpretation and field surveys. Afterwards, with the aim of evaluating the thickness of soil deposits and assessing the overall capability of the area for agro-pastoral purposes, a pedological survey was carried out by designing a 250 by 250 m sample grid within the study area. The new cores were collected through an Ejikelkamp hand auger, using an Edelman head for sediment. For this purpose, the depth of the samples was checked in the field with the uncertainty estimated as ± 0.05 m, while the description of sediments was derived from the previous literature (ERSA, 2006).

Table 1. Chronological spans of the archaeological features presented in the Main Map. For the Protohistoric period, it was adopted the chronological system proposed by Cardarelli (2009).

Chronological span	Absolute dating	Identified features
Prehistoric period	Around 10000 BC – 2200 BC	Scattered materials dated back to a period spanning from Mesolithic to Copper Age
Protohistoric period	Around 2200 BC – end of third century BC	Structures and associated finds dated back to the Bronze and Iron Ages
Roman Period	second century BC – 476 AD	Structures and associated finds dated back to the Roman period
Modern-contemporary period	nineteenth to twentieth century	Structures dated back to the late Modern-Contemporary period
Undefined	–	Features having lacking, patchy or unreliable chronological attribution

4. Results

4.1. Archaeological features

The archaeological complexes present in the studied area and reported in the Main Map are briefly described in the following sub-paragraphs and listed in chronological order.

4.1.1. Prehistoric period

Scattered prehistoric finds (Main Map, n. 1).

The earliest human presence in the area is testified by some prehistoric flint artefacts and rare tools, such as three triangles and a backed point found in the area of Mt. Stena (Bernardini, 2007, p. 86, Plate 1: 1–4) and dated to the Mesolithic (Bernardini, 2007; Biagi, Starnini, & Voytek, 2008; Guerreschi, 1998). They most probably show that this territory was visited in this period for reasons related to hunting activities. Other few flint tools from the same zone can be attributed to younger prehistoric phases. A single flint bladelette was discovered during the recent survey on the Mt. Cocusso (Main Map. n. 2) and could be perhaps related to prehistoric hunting activities, such as the Mesolithic artefacts of Mt. Stena.

Traces of early use of the area are also shown by a broken flint arrowhead found in the western part of the area (Main Map, n. 1; Figure 6, 1). This type of arrowhead, having short wings and short peduncle, is attested between the Neolithic and the Copper Age over a wide area including at some close caves of the Trieste Karst (e.g. Gilli & Montagnari, 1993, p. 153, Fig. 73, pp. 728–731). It is worth mentioning that a probable peduncle of a flint arrowhead was found in the area of Mt. Stena too (Bernardini, 2007, p. 86, Plate 1:10).

4.1.2. Protohistoric period

Supposed protohistoric burial mound of Mt. Cocusso (Main Map, n. 2).

Remain of a putative protohistoric mound located on Mt. Cocusso. Firstly described by Marchesetti (1903, p. 32) and consisting of dry stone blocks, it is considered an ancient structure for its shape and building technique, well comparable to similar ones found in Istria and Friuli that are generally dated to the first half of the second millennium BC (Calosi & Bernardini, 2012, p. 138; Flego & Rupel, 1993, p. 177).

Supposed protohistoric stoneworks, and cairns in the area of Mandarje (Main Map, n. 3).

Remains of stoneworks and cairns in the area called Mandarje, located in the north-western part of the studied area on the border between Italy and Slovenia. Some of them were cut by some modern structures reported in the FCM (Figure 3). Based on the building techniques and proximity to the large hill fort of Veliko Gradišče, these structures have been assigned to the protohistoric period and interpreted as enclosed fields related the agro-pastoral use of the area (Bernardini & Vinci, 2016, p. 80 and Figure 3). In the Classic Karst Region, similar structures were also found next to other protohistoric hill forts, such as Tabor pri Vrabčah (Mlekuž, 2015).

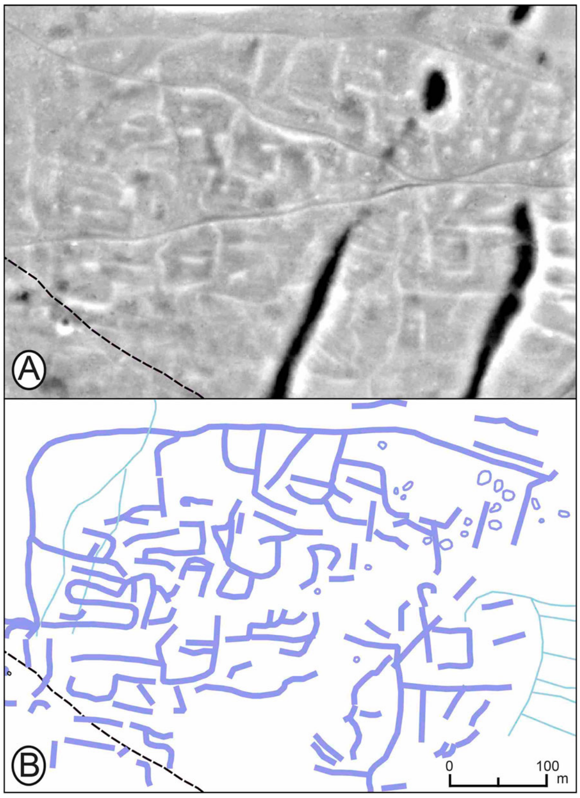

Figure 3. Remains of supposed protohistoric field divisions in the area of Mandarje. (A) Local dominance visualization of DEM (10–20 m search radius); (B) vectorized structures (blue), modern field divisions recorded in the FCM (light blue), cairns (grey).

4.1.3. Roman period

Roman building (Main Map, n. 4).

Traces of a large ancient structure of about 1 ha assigned to the Roman period for its shape and orientation (Auriemma & Karinja, 2007; Bernardini et al., 2018a). Some of the wall structures, recognizable on the field as modest ridges of few decimetres high, are covered by modern dry walls recorded in the FCM (Figures 2 and 4).

It is featured by an L-shaped body in the north-eastern part with a main rectangular eastern building of about 20 by 60 m containing at least one transversal wall which overlooks a quadrangular courtyard of about 50 by 50 m. A similarly oriented building of about 20 by 20 m lies approximately 30 m south of the rectangular construction. The orientation of the buildings (15–18 degrees W of the N) is similar to that of the Grociana piccola inner structure (Main Map, n. 6 and *infra*) and the nearby possible field division system (Main Map, n. 5b and *infra*).

Roman land divisions (Main Map, n. 5 a-b-c).

Remains of Roman land division systems covered by modern land division structures reported in the FCM (Figure 5). A N–W/S–E oriented linear major tract (about 1300 m) has been recognized in the central part of the studied area and it extends in the south-eastern part with a minor tract of about 350 m (Main Map, n. 5a). Parallel structures perpendicular to the former were recognized in ALS-derived images in the surrounding of the modern village of Pesek (south-western part of the study area, Main Map, n. 5b). Similar orientations of about 42 degrees E of N have been identified also elsewhere in the Classic Karst region (Bernardini et al., 2018a, Supplementary S15; Mlekuž 2018). While such orientation is not reported from the structures of Tergeste (Braini, 2011), it matches the orientation of the inner structures of the large San Rocco military fortification, already built during the second century BC, probably in connection with the first Roman conquest of the area (Bernardini et al., 2015).

Other possible Roman features interpreted as a part of the land division system are located N of the path of a detected Roman road (Main Map, n. 7 and *infra*) with the southernmost main wall starting from the road

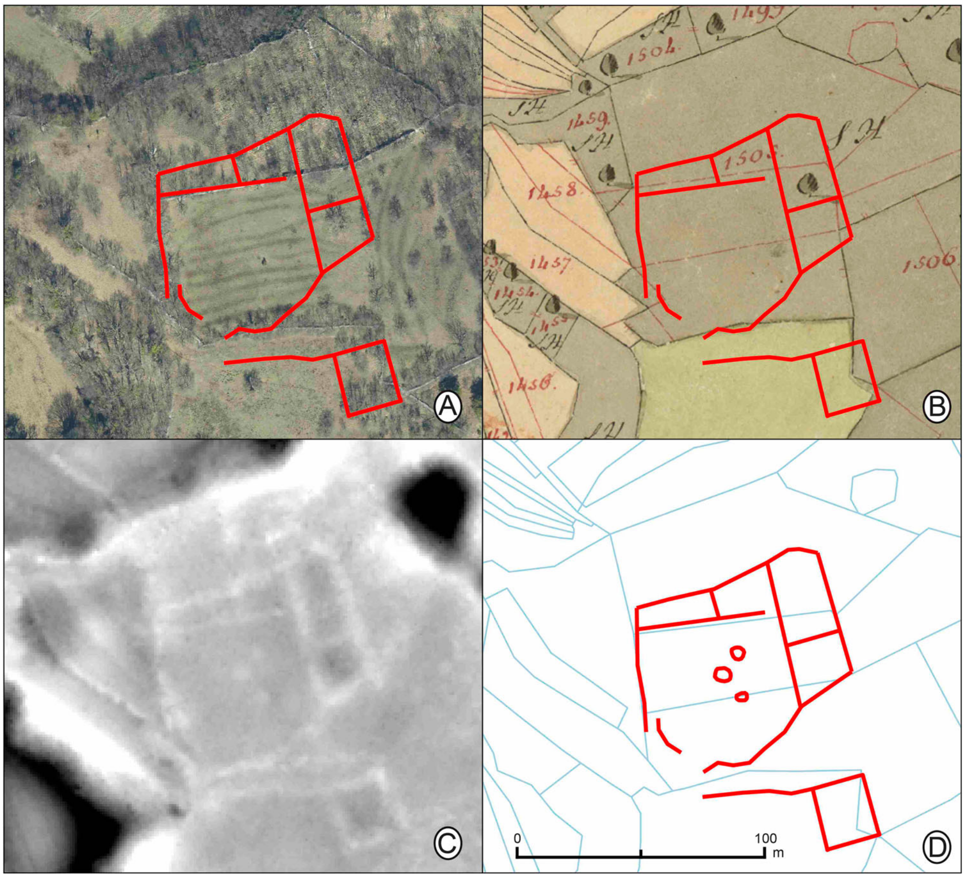

Figure 4. Remain of probable Roman building in the north-western part of the investigated area. (A) Orthophoto (2003) and plan of the vectorized structures; (B) FCM of the area (from: Archivio di Stato di Trieste) and plan of the vectorized structures; (C) Local Dominance visualization of DEM (10–20 m search radius); (D) vectorized structures (red), modern field divisions recorded in the FCM (light blue), cairns or other possible structures (red circles).

itself (Main Map, n. 5c). They were detected on the ground as rectilinear modest ridges and covered by modern land division structures reported in the FCM. They are featured by two parallel main walls, about 200 m long with minor structures between them and show an orientation of about 14 degrees W of N, slightly different to that of the inner fortification of Mt. Grociana piccola (about 18–22 degrees N–W, Bernardini et al., 2018a: Fig 5B and S12).

Roman military fortifications of Grociana Piccola (Main Map, n. 6).

Remains of Roman Republican fortifications featured by a trapezoidal structure with rounded angles (about 160 × 95 × 170 × 120 m) E–W oriented, housing a smaller rectangular one (100 × 43 m) with a different orientation of about 18 degrees tilted from the horizontal E–W direction. The remains of the external wall are recognizable as a small ridge (3–4 m wide and less than 1 m high) while the ruins of the inner rectangular fortification are detectable as a more imposing ridge of about 6 m in width and 1–2 m in height. Two main *clavicula*-shaped entrances have been recognized, respectively located on the northern and on the eastern side of the larger structure, of which the latter was not published in previous contributions. Archaeological surface and metal detector surveys within and in the surroundings of the camp allowed to collect tens of Roman shoe hobnails mostly dated back to the late Republican period, amphorae and pottery fragments (Bernardini, 2019; Bernardini et al., 2015, 2018a).

Roman road (Main Map, n. 7).

Remains of a main Roman road, possibly connecting the Roman centres of *Aquileia* and *Tergeste* with *Tarsatica*, whose itinerary has been reconstructed for more than 4 km. It is featured by several tracks of about 8–10 m width in some parts cut into the limestone and prepared with gravel. Over 200 Roman shoe hobnails of both Republican and Imperial period were found within or close to the route (Bernardini et al., 2018a; Figures 6, 2).

In the central part of the identified path, the road is interrupted by at least one large sinkhole, possibly originated by an underlying cave below, whose likely presence has been revealed by geophysical surveys. All gathered data suggest to place the formation of the sinkhole and the depression existing nowadays after Roman times and to attribute the disruption of the road to the transfer of soil from the karst depression into the cave (Bernardini et al., 2018a).

Roman structures in the area of Merišče (Main Map, n. 8).

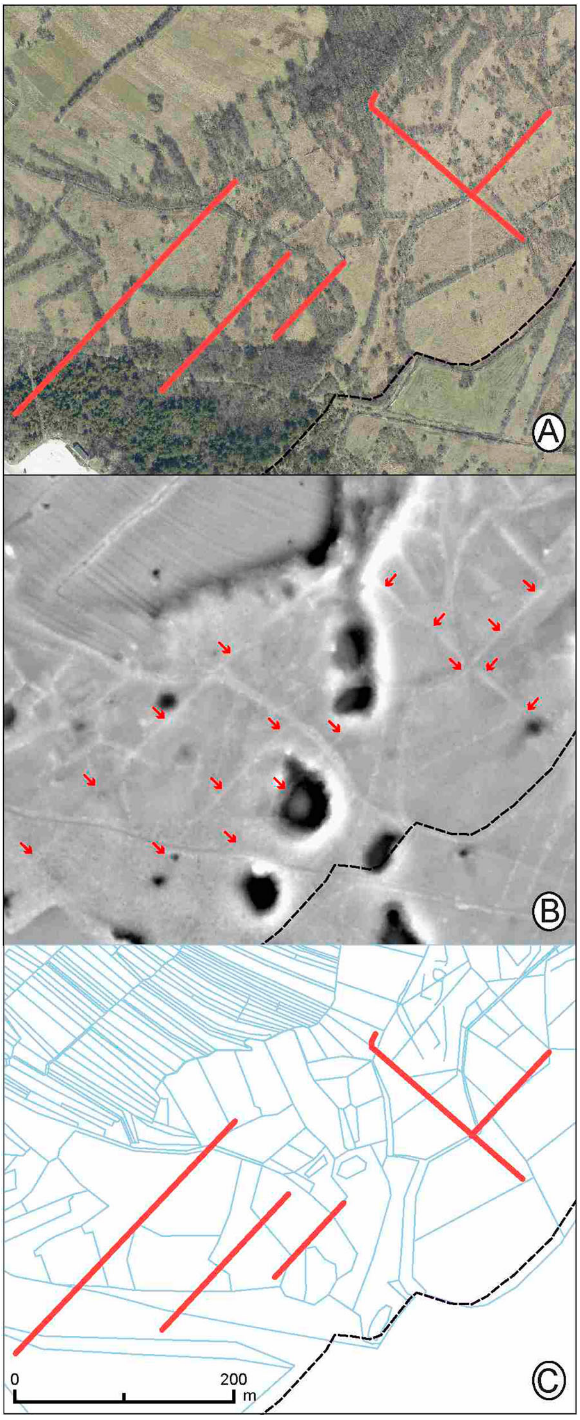

Figure 5. Remain of Roman land divisions in the south-eastern area. (A) Orthophoto (2003) and plan of the vectorized structures; (B) Vectorized structures (indicated by red arrows) superimposed to the Local Dominance visualization of DEM (10–20 m search radius); (C) vectorized structures (red), modern field divisions recorded in the FCM (light blue).

Remains of Roman structures, located in the southern part of the studied area N of the modern village of Draga S. Elia, locally known as Merišče. It was already known from early '90 and is featured by modest ridges with associated materials (tile fragments and pottery jigsaw pieces) assigned the Roman period (Flego & Županči̇č, 1991, pp. 57–58; Figure 7) and mapped in detail through ALS. It is featured by long parallel possibly enclosing terraces S–W/N–E oriented.

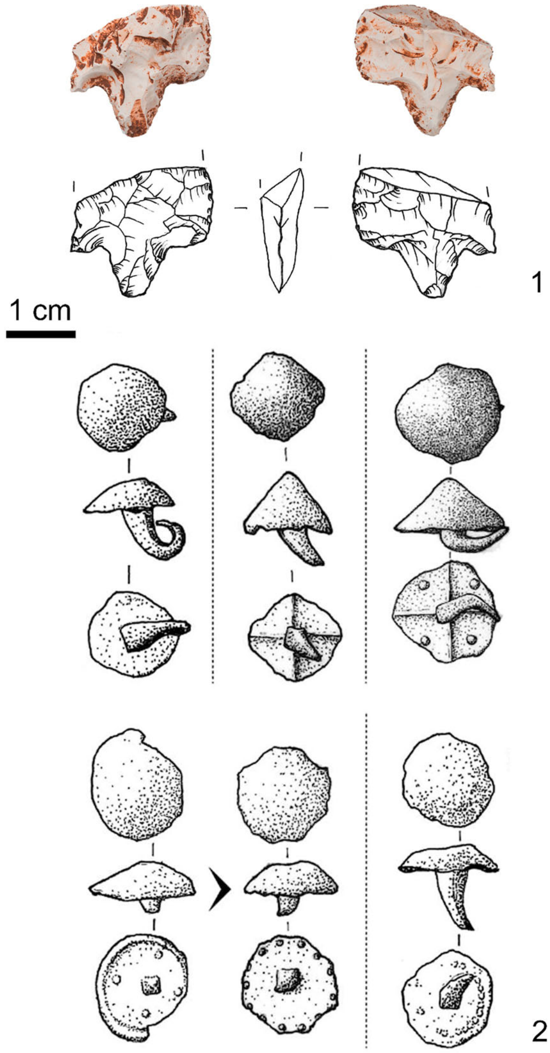

Figure 6. (A) Flint arrowhead found at surface in the western part of the studied area. Black tic marks on the drawings indicate the reconstructed prosecution of the arrowhead's profile; (B) Different types of hobnails found at surface along the identified Roman road tracks (after Bernardini et al., 2018a, Figure 5). Photo by V. Macovaz and drawings by A. Fragiacomo.

A rectangular structure of about 40 m by 30 m with a central courtyard is visible in the north-eastern part of the area. By comparison, this structure looks similar to the probable Roman building located in the north-eastern area (Main Map, n. 4 and see *supra*). The presence of Roman land division features around this building is in agreement with the interpretation of this complex as a small *vicus*, as proposed by Flego and Županči̇č (1991).

4.1.4. Modern-contemporary period

Remain of lime kilns, icehouses, and ponds (Main Map, n. 9 a-b).

A few circular icehouses are attested. They consist of deep wells made of dry stone masonry built in the early nineteenth and first half of twentieth centuries to store ice supplies. Two main clusters of these structures are present in the area N of Draga S. Elia (Main Map, n. 9a; Figure 8(A)) and W of Grozzana. They are

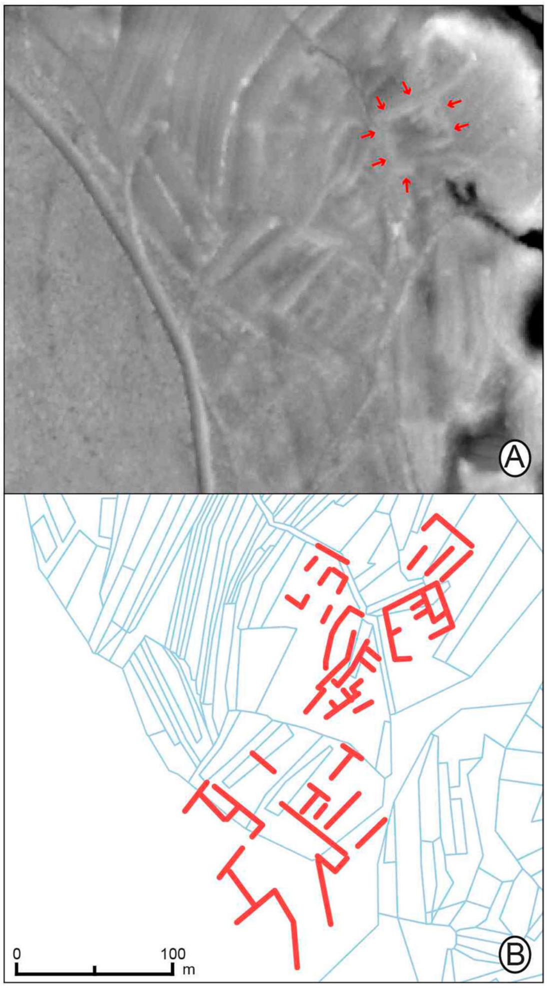

Figure 7. Remains of Roman land divisions in the area of Merišče. (A) Local Dominance visualization of DEM (10–20 m search radius). The red arrows indicate the area of the rectangular complex; (B) digitized structures (red), modern field divisions recorded in the FCM (light blue).

generally close to small artificial ponds (Figure 8(B)) from which the ice was extracted during the winter season.

Other circular structures with earthen raised edges are remains of temporary kilns for the production of lime (Main Map, n. 9b). Similar structures were traditionally built and use by the local population until the nineteenth century and their remains are widespread over the whole Karst region, mainly at the bottom of dolines.

Military trenches of the First and Second World War (Main Map, n. 10)

Several trenches dug in the first half of the twentieth century are attested in the area and well visible in the ALS-derived images. Some of them were probably used as a military training camp during the First World War and were restored and reuse during the Second World War.

Terraces, buildings, paths and other features of undetermined period (Main Map, n. 11 a-b-c-d).

Remains of terraces and orthogonal walls in the S–W part of the studied area covered by later structures recorded in the FCM. Main structures have a N–W/S–E orientation which follows the natural slope of the hill (Main Map, n. 11a). S of these terraces, an elongated curvilinear track was recognized (Main Map, n. 11b). Other wall structures interpreted as terraces are located in the central part of the studied area (Main Map, n. 11c), close to the finding of a probable N–S oriented path (Main Map, n. 11d). As some of these are covered or cross-cut by features mapped in the FCM, they can be attributed to a previous period. A possible attribution to the Roman times can be tentatively proposed for a roughly rectangular structure, most probably a building, of about 20 m by 14 m dimensions (Main Map, n. 11e). This is located south of the Roman building in the N–W side of the map (Main Map, n. 4).

4.2. Karst landforms, lithostratigraphic units and soil thickness

Most of the area is dominated by a wide karst plateau relatively flat, locally remodeled by human activities. Light-grey limestone beds generally dipping toward S–E outcrop. The plateau is riddled by 189 dolines, which represent the most significant mesoscale epigean karst landforms in the area (Figure 9(A)). They have a variable width ranging from few meters to about 200 m, only 27 of which of them exceed a width of 100 m. About 25 of them host red soil deposits at their bottom over an estimated surface larger than

Figure 8. (A) Circular dry stones icehouse located N of Draga S. Elia; (B) Remains of a small pond located in the same area.

1000 m² (Main Map). Other typical karst landforms are the caves, that are widespread in the whole studied area and showing peculiarities in shape and dimensions (Figure 9(B); RAFVG, 2017). The human occupation of the caves is well documented in the whole Karst and is attested elsewhere in the studied area (Flego & Županči̇č, 1991, p. 19). Traces of palaeofluvial erosion are indicated by some dry valleys present in the area, generally having a V-shaped profile (Figure 9(C,D); Main Map). Vegetation bushes and grassland generally covering the underlying rocks are widespread in the studied area (Figure 9(E)) and often correspond to pastures or limited cultivated fields. Differently, on the southern slopes of Mt. Cocusso and Mt. Goli as well as on the several slopes of V-shaped valleys, outcrops of massive limestone beds occur (Figure 9(F); Main Map).

The pedological survey was carried out to evaluate the land capabilities for agro-pastoral purposes. Dolines were not considered in this survey as they are well known to have been exploited for agriculture purposes until recent times. In fact, having well developed reddish clayey soils sometimes thicker than 4 m and offering protection from the wind, dolines constitute the preferential locations for traditional agriculture in the Karst (Novaković, Simoni, & Mušič, 1999; Fabec, 2012). The surveys carried out allowed to detail the information already reported by ERSA (2006). The only sector where deep soils have been found in the studied area is represented by the narrow valley located south of the village of Grozzana. Here, quaternary reddish clayey deposits up to 12 m thick previously classified as Rhodi-Profondic Luvisol (ERSA, 2006: UC E9) were identified. N of the modern town of Draga S. Elia, reddish clayey soils developed from the alteration of the Flysch bedrock were surveyed. These soils classified as Calcari-Epileptic Cambisol (ERSA, 2006: F3) have an average depth of about 0.4 m. The remaining area consists of reddish silt and clayey-silt soils of limited thickness, generally thinner than 0.3 m or almost absent (less than 0.15 m and generally around 0.05–0.10 m), classified as Rendzic Leptosol, Epileptic Phaeozem and Lithic Leptosol (ERSA, 2006: E13, E7, E12, E6). It appears meaningful that several detected archaeological structures such as those in the surroundings of the Roman building (Main Map, n. 4), Merišče (Main Map, n. 8), Mandarje (Main Map, n. 3) and Mt. Goli (Main Map, n. 11a) as well as some areas in the surroundings of the detected Roman field divisions (Main Map, n. 5a, 5b, 5c) are

Figure 9. Landscape and landforms in the area of Grozzana. (A) doline; (B) cave; (C) dry karst valley; (D) flat valley filled by Quaternary deposits; (E) karstic land covered by vegetation; (F) outcropping limestone beds.

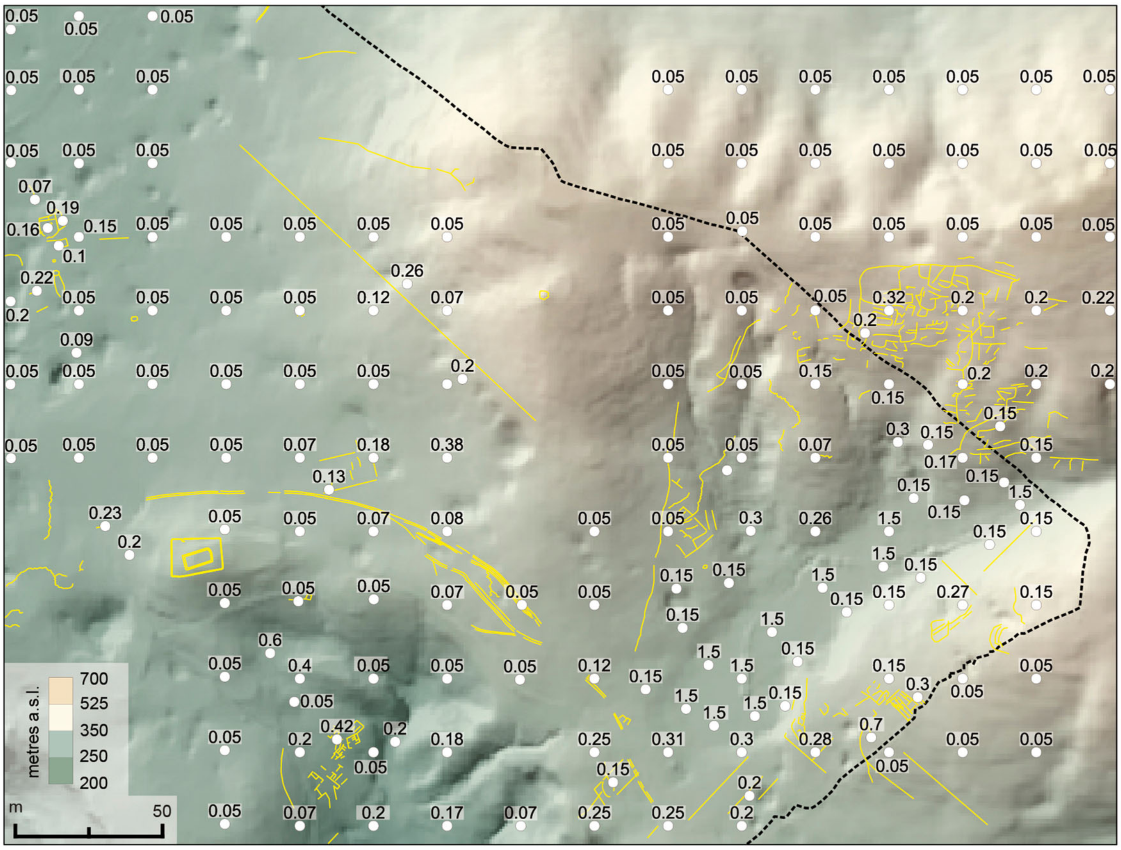

Figure 10. DEM of the area and plan of the cores with respect to the archaeological features. The numbers indicate the thickness of soil deposits.

located in areas where soils are generally thicker than 0.15 cm. Similarly, most of these areas have been exploited in different periods, at least from Roman until the nineteenth century, as suggested by the presence of a dense field system in the FCM (Figure 10; Main Map).

5. Discussion and conclusions

Until recent years only a few surface prehistoric finds, the mound of Mt. Cocusso, the Merišče and Grociana piccola sites, were known in the studied area though the latter context was wrongly interpreted as a pre-Roman settlement (Flego & Rupel, 1993; Marchesetti, 1903). The analysis of ALS-derived images and the use of combined techniques allowed to riddle the map with a significant number of archaeological features and to specify in many cases their shape, chronology and possible functions. The chronological attribution of the features of this palimpsest was based on cross-cutting stratigraphic relationships with early nineteenth century structures reported by the FCM, shape, orientation, building techniques and associated archaeological finds. This allowed to enlighten what some authors defined recently as the 'archaeological continuum' of the area (Campana, 2018).

A few prehistoric flint artefacts demonstrate an ephemeral human presence in the area since Mesolithic times probably connected to hunting activities. Though traces of protohistoric settlements are not attested so far in the studied area, tangible traces of this period are likely the remains of the Mt. Cocusso mound and the Mandarje land division system, both probably related to the nearby Veliko Gradišče hill fort, located just some hundred meters N–E of the investigated area (Bernardini & Vinci, 2016; Marchesetti, 1903; Petru, 1975, p. 136). With the advent of the Roman period, the impact of human activities on the landscape increases with the construction of military fortifications, roads, small settlements, large buildings and regularly planned land division systems, which considerably contributed to remodel the natural landscape. Almost absent or unreliable are the archaeological data about the Grozzana landscape in Medieval and Modern times. Some Modern-Contemporary structures identified include military trenches, icehouses, lime kilns and field divisions, the latter recorded in the FCM.

Though sedimentological data of dolines infillings in a close sector of the Karst were interpreted as evidence of regional soil erosion events in last 5000 years (Fabec, 2012), the archaeological data here presented do not support a considerable change in the soil distribution and thickness since protohistory, at least in the investigated area. This is testified by the good preservation of ephemeral structures in areas covered by very thin soil, such as the external fortification of Grociana piccola, the finding of tiny prehistoric Mesolithic flints found at surface together with modern finds.

Therefore, the existence of few limited areas suitable for agro-pastoral purposes appears to have affected the evolution of the rural landscape. In fact, whereas the settlement organization has significantly changed through time, cultivated fields and pastures, documented by both Roman and early nineteenth century field divisions (Main Map), have been clustered over some specific areas where deeper soils are present. It differs the area of Mandarje, probably used during protohistoric times, where agro-pastoral activities were likely carried out under control and protection of the large fortified settlement of Veliko Gradišče.

As a final remark, it is important to enlighten the potential use of this map for different scopes including the protection and valorization of the cultural and environmental heritage and land use planning. On this line, the accordance with the Regione Autonoma Friuli Venezia Giulia map standards makes desirable the future development of the proposed cartography at the regional scale.

Software

DTMs were produced in SAGA GIS. Most of the remaining work (analysis, visualization, map design) was done in QGIS. Adobe Illustrator was used to improve the graphics of the map. The v.surf.rst interpolation algorithm available in Grass Gis 7 was used to create the bathymetric map of soil depth from collected cores.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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